

1 **What is claimed is:**

2 1. A method of defining a storage format in multiple data storage
3 devices, each data storage device having a plurality of storage media and a
4 plurality of corresponding data transducer heads, each transducer head for
5 recording on and playback of information from a corresponding storage medium
6 in multiple zones, the method comprising the steps of:

7 (a) (1) for a sample number of data storage devices, measuring a
8 performance of each head in the sample number of data storage devices at one
9 or more read/write frequencies per zone, and

10 (2) for said multiple data storage devices, based on said
11 performance measurements, jointly: selecting a group of read/write frequencies,
12 two or more read/write frequencies for each zone, and allocating one or more of
13 the heads in each of the multiple data storage devices to each frequency in said
14 group of frequencies per zone; and

15 (b) in each of said multiple data storage devices, assigning one of said
16 frequencies to each head per zone, based on capability of that head.

17
18 2. The method of claim 1, wherein in step (a)(1) measuring
19 performance of each head further includes the steps of measuring a
20 record/playback performance of that head at one or more read/write frequencies.

21
22 3. The method of claim 1, wherein in step (a)(1) measuring
23 performance of each head further includes the steps of measuring a
24 record/playback performance of that head at multiple storage medium locations.

25
26 4. The method of claim 1, wherein in step (a)(1) measuring
27 performance of each head further includes the steps of measuring a
28 record/playback performance of that head according to a performance metric at
29 different frequencies.

1 5. The method of claim 4, wherein said performance metric includes
2 symbol error rate on track, symbol error rate off track, mean squared error on
3 track, and mean squared error off track.

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5 6. The method of claim 1, wherein step (a) is performed in a format
6 design process and step (b) is performed in a test process.

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8 7. The method of claim 6, wherein the format design process is part of
9 storage device design phase and the test process is part of storage device
10 manufacturing phase.

11

12 8. The method of claim 1, wherein step (a)(1) further includes the
13 steps of calibrating each of said multiple data storage devices for each said
14 frequencies.

15

16 9. The method of claim 1, wherein step (a)(2) further includes the
17 steps of jointly selecting said frequencies and allocating said heads to said
18 frequencies, to satisfy a specified constraint.

19

20 10. The method of claim 9, wherein:

21 step (a)(1) further includes the steps of, for each of said sample
22 number of data storage devices:

23 selecting a performance metric for the heads in that data
24 storage device for each zone; and

25 measuring performance of each head at different
26 frequencies per zone based on said metric;

27 step (a)(2) further includes the steps of, for the multiple data
28 storage devices:

29 based on said performance measurements, for each zone
30 allocating an integral number of heads to each of said frequencies for that zone
31 to satisfy

1 the specified constraint.

2

3 11. The method of claim 10, wherein in step (a)(2) allocating said
4 heads to said frequencies per zone further includes the steps of: for each zone,
5 based on the performance of the heads in a plurality of zones, allocating an
6 integral number of heads to each of said frequencies for that zone to satisfy said
7 constraint for said multiple data storage devices.

8

9 12. The method of claim 10, wherein step (a)(2) further includes the
10 steps of:

11 based on said performance measurements, generating
12 record/playback frequency capability distributions of the heads in the sample
13 number of disk drives, at each zone for a target performance metric, and

14 based on said distributions, allocating an integral number of heads
15 to each of said frequencies for that zone to satisfy said constraint for the said
16 multiple data storage devices.

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18 13. The method of claim 9, wherein said constraint comprises providing
19 a required data storage capacity for each of said multiple data storage devices.

20

21 14. The method of claim 9, said constraint comprises providing a
22 required data storage device yield for said multiple data storage devices.

23

24 15. The method of claim 9, wherein said constraint comprises
25 maximizing the data storage device yield while providing a specified data storage
26 device capacity of the multiple data storage devices.

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28 16. The method of claim 9, wherein said constraint comprises
29 maximizing the data storage capacity for each of the multiple data storage
30 devices while providing a specified data storage device yield.

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1 17. A method of defining a storage format in multiple data storage
2 devices, each data storage device having a plurality of storage media and a
3 plurality of corresponding data transducer heads, each transducer head for
4 recording on and playback of information from a corresponding storage medium
5 in multiple zones, the method comprising the steps of:

6 (a) (1) for a sample number of data storage devices, measuring a
7 performance of each head in the sample number of data storage devices at one
8 or more read/write frequencies per zone, and based on said performance
9 measurements, generating performance distributions of the heads in said sample
10 number of data storage devices, at each zone for a target performance metric,
11 and

12 (2) for said multiple data storage devices, based on said
13 performance distributions, jointly: selecting a group of read/write frequencies, two
14 or more read/write frequencies for each zone, and allocating one or more of the
15 heads in each of the multiple data storage devices to each frequency in said
16 group of frequencies per zone; and

17 (b) in each of said multiple data storage devices, assigning one of said
18 frequencies to each head per zone, based on capability of that head.

19
20 18. The method of claim 17, wherein generating said distributions
21 further includes the steps of:

22 estimating record/playback frequency capability of each head
23 based on said measurements, and
24 generating record/playback frequency capability distributions of the
25 heads at each zone for a target performance metric based on said estimated
26 record/playback frequency capabilities the heads.

27
28 19. The method of claim 17, wherein the steps of generating said
29 distributions is performed in a post-processing phase.

30

1 20. The method of claim 17, wherein generating said distributions
2 includes the steps of: generating record/playback frequency capability
3 distributions of the heads based on said performance measurements at a target
4 performance metric for the heads in said sample number of data storage devices.

5

6 21. The method of claim 17, wherein in step (a)(2) selecting said group
7 of frequencies further includes the steps of selecting said group of frequencies to
8 satisfy a specified constraint.

9

10 22. The method of claim 17, wherein said performance metric includes
11 symbol error rate on track, symbol error rate off track, mean squared error on
12 track, and mean squared error off track.

13

14 23. A method of defining a storage format in multiple data storage
15 devices, each data storage device having a plurality of storage media and a
16 plurality of corresponding data transducer heads, each transducer head for
17 recording on and playback of information from a corresponding storage medium
18 in multiple zones, the method comprising the steps of:

19 (a) (1) for a sample number of data storage devices, measuring a
20 performance of each head in the sample number of data storage devices at one
21 or more read/write frequencies per zone, and

22 (2) for said multiple data storage devices, based on said
23 performance measurements, jointly: selecting a group of read/write frequencies,
24 two or more read/write frequencies for each zone, and for each zone allocating
25 an integral number of heads to each of said frequencies for that zone to satisfy a
26 constraint; and

27 (b) in each of said multiple data storage devices, assigning one of said
28 frequencies to each head per zone, based on capability of that head and said
29 allocation of the heads.

30

1 24. The method of claim 23, wherein step (b) further includes the steps
2 of, for each of said multiple data storage devices:

3 (i) obtaining record/playback performance of each head at a
4 performance metric per zone at one of said read/write frequencies;

5 (ii) for each zone, ranking the heads from best to worst
6 according to the performance metric; and

7 (iii) assigning said allocated number of heads, according to the
8 ranking, to one of said read/write frequencies.

9
10 25. The method of claim 24, further comprising the steps of:

11 repeating steps (i)-(iii) for the remaining heads at the other
12 read/write frequencies.

13
14 26. The method of claim 24, wherein steps (i)-(iii) are repeated for each
15 of said frequencies, starting from the highest frequency to the lowest frequency.

16
17 27. The method of claim 24, wherein: step (ii) further includes the steps
18 of selecting said performance metric for the heads in that data storage device for
19 each zone.

20
21 28. The method of claim 23, wherein for each head in said multiple
22 data storage devices, said number of zones are on different storage media in
23 each data storage device.

24
25 29. The method of claim 23, wherein for each head in said multiple
26 data storage devices, said number of zones are on the same storage media in
27 each data storage device.

28
29 30. The method of claim 23, wherein in step (a)(2) said specified
30 criteria comprises providing a specified data storage capacity for each of the
31 multiple data storage devices while maximizing a data storage device yield.

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2 31. The method of claim 23, wherein in step (a)(2) said specified
3 criteria comprises maximizing the data storage capacity for each of the multiple
4 data storage devices while providing a specified data storage device yield.

5
6 32. The method of claim 23, wherein step (b) further includes the steps
7 of calibrating each data storage device for each frequency.

8
9 33. A method of defining a storage format in multiple data storage
10 devices, each data storage device having a plurality of storage media and a
11 plurality of corresponding data transducer heads, each transducer head for
12 recording on and playback of information from a corresponding storage medium
13 in multiple zones, the method comprising the steps of:

14 (a) (1) for a sample number of data storage devices, measuring
15 a performance of each head in the sample number of data storage devices at
16 one or more read/write frequencies per zone, and

17 (2) for said multiple data storage devices, based on said
18 performance measurements, jointly: selecting a group of read/write frequencies,
19 two or more read/write frequencies for each zone, and allocating one or more of
20 the heads in each of the multiple data storage devices to each frequency in said
21 group of frequencies per zone; and

22 (b) in each of said multiple data storage devices, assigning one
23 of said frequencies to each head per zone, based on capability of that head;

24 wherein in each of said multiple data storage devices:

25 said multiple zones on each storage media are arranged as
26 concentric zones, each zone having an inner and an outer boundary at different
27 radial locations on the storage media,

28 such that each storage media includes the same number of
29 concentric zones as other storage media in that data storage device, such that
30 the boundaries of radially similarly situated zones on all the storage media in that
31 data storage device are at the same radial locations.

1
2 34. The method of claim 33, wherein radially similarly situated zones on
3 all the storage media include the same number of concentric tracks.

4
5 35. The method of claim 33, wherein at least a number of radially
6 similarly situated zones on all the storage media include different number of
7 concentric tracks.

8
9 36. A method of defining a storage format in multiple data storage
10 devices, each data storage device having a plurality of storage media and a
11 plurality of corresponding data transducer heads, each transducer head for
12 recording on and playback of information from a corresponding storage medium
13 in multiple zones, the method comprising the steps of:

14 (a) (1) for a sample number of data storage devices, measuring
15 a performance of each head in the sample number of data storage devices at
16 one or more read/write frequencies per zone, and

17 (2) for said multiple data storage devices, based on said
18 performance measurements, jointly: selecting a group of read/write frequencies,
19 two or more read/write frequencies for each zone, and allocating one or more of
20 the heads in each of the multiple data storage devices to each frequency in said
21 group of frequencies per zone; and

22 (b) in each of said multiple data storage devices, assigning one
23 of said frequencies to each head per zone, based on capability of that head;

24 wherein in each of said multiple data storage devices:

25 said multiple zones on each storage media are arranged as
26 concentric zones, each zone having an inner and an outer boundary at different
27 radial locations on the storage media,

28 such that each storage media includes a sequence of concentric
29 zones, such that the boundaries of at least a number sequentially similarly
30 situated zones on different storage media in that data storage device are at
31 different radial locations.

1
2 37. The method of claim 36, wherein sequentially similarly situated
3 zones on all the storage media include the same number of concentric tracks.
4

5 38. The method of claim 36, wherein at least a number of sequentially
6 similarly situated zones on all the storage media include different number of
7 concentric tracks.
8

9 39. A data storage device comprising a plurality of pairs of storage
10 media surfaces and transducer heads, each transducer head for recording on
11 and playback of information from a corresponding storage medium in multiple
12 zones, and a controller that controls the heads for reading and writing data on the
13 media surfaces, the controller being programmed to write data in a storage
14 format defined by the steps including:

15 (a) (1) for a sample number of data storage devices, measuring a
16 performance of each head in the sample number of data storage devices at one
17 or more read/write frequencies per zone, and

18 (2) for said data storage device, based on said performance
19 measurements, jointly: selecting a group of read/write frequencies, two or more
20 read/write frequencies for each zone, and allocating one or more of the heads in
21 that data storage devices to each frequency in said group of frequencies per
22 zone; and

23 (b) in said data storage device, assigning one of said frequencies to
24 each head per zone, based on capability of that head, thereby defining said
25 storage format.

26
27 40. The data storage device of claim 39, wherein in step (a)(1)
28 measuring performance of each head further includes the steps of measuring a
29 record/playback performance of that head according to a performance metric at
30 different frequencies.

1 41. The data storage device of claim 39, wherein step (a) is performed
2 in a storage device design phase and step (b) is performed in a storage device
3 manufacturing phase.

4

5 42. The data storage device of claim 39, wherein step (a)(1) further
6 includes the steps of calibrating each of said multiple data storage devices for
7 each said frequencies.

8

9 43. The data storage device of claim 39, wherein step (a)(2) further
10 includes the steps of jointly selecting said frequencies and allocating said heads
11 to said frequencies, to satisfy a specified constraint.

12

13 44. The data storage device of claim 43, wherein:
14 step (a)(1) further includes the steps of, for each of said sample
15 number of data storage devices:

16 selecting a performance metric for the heads in that data
17 storage device for each zone; and

18 measuring performance of each head at different
19 frequencies per zone based on said metric;

20 step (a)(2) further includes the steps of, for the multiple data
21 storage devices:

22 based on said performance measurements, for each zone
23 allocating an integral number of heads to each of said frequencies for that zone
24 to satisfy the specified constraint.

25 /

26 45. The data storage device of claim 44, wherein in step (a)(2)
27 allocating said heads to said frequencies per zone further includes the steps of:
28 for each zone, based on the performance of the heads in a plurality of zones,
29 allocating an integral number of heads to each of said frequencies for that zone
30 to satisfy said constraint for said multiple data storage devices.

31

1 46. The data storage device of claim 44, wherein step (a)(2) further
2 includes the steps of:

3 based on said performance measurements, generating
4 record/playback frequency capability distributions of the heads in the sample
5 number of disk drives, at each zone for a target performance metric, and

6 based on said distributions, allocating an integral number of heads
7 to each of said frequencies for that zone to satisfy said constraint for the said
8 multiple data storage devices.

9
10 47. The data storage device of claim 44, wherein said constraint
11 comprises providing a required data storage capacity for each of said multiple
12 data storage devices.

13
14 48. The data storage device of claim 43, said constraint comprises
15 providing a required data storage device yield for said multiple data storage
16 devices.

17
18 49. The data storage device of claim 43, wherein said constraint
19 comprises maximizing the data storage device yield while providing a specified
20 data storage device capacity of the multiple data storage devices.

21
22 50. The data storage device of claim 43, wherein said constraint
23 comprises maximizing the data storage capacity for each of the multiple data
24 storage devices while providing a specified data storage device yield.

25
26 51. A data storage device comprising a plurality of pairs of storage
27 media surfaces and transducer heads, each transducer head for recording on
28 and playback of information from a corresponding storage medium in multiple
29 zones, and a controller that controls the heads for reading and writing data on the
30 media surfaces, the controller being programmed to write data in a storage
31 format defined by the steps including:

1 (a) (1) for a sample number of data storage devices, measuring a
2 performance of each head in the sample number of data storage devices at one
3 or more read/write frequencies per zone, and based on said performance
4 measurements, generating performance distributions of the heads in said sample
5 number of data storage devices, at each zone for a target performance metric,
6 and

7 (2) for the data storage device, based on said performance
8 distributions, jointly: selecting a group of read/write frequencies, two or more
9 read/write frequencies for each zone, and allocating one or more of the heads in
10 each of the multiple data storage devices to each frequency in said group of
11 frequencies per zone; and

12 (b) in the data storage devices, assigning one of said frequencies to
13 each head per zone, based on capability of that head.

14
15 52. The data storage device of claim 51, wherein generating said
16 distributions further includes the steps of:

17 estimating record/playback frequency capability of each head
18 based on said measurements, and

19 generating record/playback frequency capability distributions of the
20 heads at each zone for a target performance metric based on said estimated
21 record/playback frequency capabilities the heads.

22
23 53. The data storage device of claim 51 wherein the steps of
24 generating said distributions is performed in a post-processing phase.

25
26 54. The data storage device of claim 51, wherein generating said
27 distributions includes the steps of: generating record/playback frequency
28 capability distributions of the heads based on said performance measurements at
29 a target performance metric for the heads in said sample number of data storage
30 devices.

1 55. The data storage device of claim 51, wherein in step (a)(2)
2 selecting said group of frequencies further includes the steps of selecting said
3 group of frequencies to satisfy a specified constraint.

4

5 56. A data storage device comprising a plurality of pairs of storage
6 media surfaces and transducer heads, each transducer head for recording on
7 and playback of information from a corresponding storage medium in multiple
8 zones, and a controller that controls the heads for reading and writing data on the
9 media surfaces, the controller being programmed to write data in a storage
10 format defined by the steps including:

11 (a) (1) for a sample number of data storage devices, measuring a
12 performance of each head in the sample number of data storage devices at one
13 or more read/write frequencies per zone, and

14 (2) for said data storage device, based on said performance
15 measurements, jointly: selecting a group of read/write frequencies, two or more
16 read/write frequencies for each zone, and for each zone allocating an integral
17 number of heads to each of said frequencies for that zone to satisfy a constraint;
18 and

19 (b) in said data storage device, assigning one of said frequencies to
20 each head per zone, based on capability of that head and said allocation of the
21 heads.

22

23 57. The data storage device of claim 56, wherein step (b) further
24 includes the steps of, for the data storage device:

25 (i) obtaining record/playback performance of each head at a
26 performance metric per zone at one of said read/write frequencies;

27 (ii) for each zone, ranking the heads from best to worst
28 according to the performance metric; and

29 (iii) assigning said allocated number of heads, according to the
30 ranking, to one of said read/write frequencies.

31

1 58. The data storage device of claim 57, wherein step (b) further
2 comprises the steps of:

3 repeating steps (i)-(iii) for the remaining heads at the other
4 read/write frequencies.

5
6 * 59. The data storage device of claim 57, wherein step (b) further
7 includes the steps of selecting said performance metric for the heads in that data
8 storage device for each zone.

9
10 60. The data storage device of claim 56, wherein in step (a)(2) said
11 specified criteria comprises providing a specified data storage capacity for the
12 data storage devices while maximizing a data storage device yield.

13
14 X61. The data storage device of claim 56, wherein in step (a)(2) said
15 specified criteria comprises maximizing the data storage capacity for each of the
16 multiple data storage devices while providing a specified data storage device
17 yield.

18
19 62. A data storage device comprising a plurality of pairs of storage
20 media surfaces and transducer heads, each transducer head for recording on
21 and playback of information from a corresponding storage medium in multiple
22 zones, and a controller that controls the heads for reading and writing data on the
23 media surfaces, the controller being programmed to write data in said multiple
24 zones, wherein:

25 said multiple zones on each storage media are arranged as
26 concentric zones, each zone having an inner and an outer boundary at different
27 radial locations on the storage media,

28 such that each storage media includes the same number of
29 concentric zones as other storage media in that data storage device, wherein the
30 boundaries of radially similarly situated zones on all the storage media in that
31 data storage device are at the same radial locations.

1

2 63. The data storage device of claim 62, wherein radially similarly
3 situated zones on all the storage media include the same number of concentric
4 tracks.

5

6 64. The data storage device of claim 62, wherein at least a number of
7 radially similarly situated zones on all the storage media include different number
8 of concentric tracks.

9

10 65. A data storage device comprising a plurality of pairs of storage
11 media surfaces and transducer heads, each transducer head for recording on
12 and playback of information from a corresponding storage medium in multiple
13 zones, and a controller that controls the heads for reading and writing data on the
14 media surfaces, the controller being programmed to write data in said multiple
15 zones, wherein:

16 said multiple zones on each storage media are arranged as
17 concentric zones, each zone having an inner and an outer boundary at different
18 radial locations on the storage media,

19 such that each storage media includes a sequence of concentric
20 zones, such that the boundaries of at least a number sequentially similarly
21 situated zones on different storage media in that data storage device are at
22 different radial locations.

23

24 66. The data storage device of claim 65, wherein sequentially similarly
25 situated zones on all the storage media include the same number of concentric
26 tracks.

27

28 67. The data storage device of claim 65, wherein at least a number of
29 sequentially similarly situated zones on all the storage media include different
30 number of concentric tracks.